ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

Final Report

On

PROJECT NO. 10 - TEST OF TRUCK, 3/4 TON, IMPROVED INSULATED AMBULANCE

Project No. 10

12 June 1943

ARMORED FORCE MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

Project No. 10
451.8 GNOML

12 June 1943

1. Final Report on: Project No. 10, Test of Truck, 3/4 Ton, Improved Insulated Ambulance.

a. Authority - See Inclosure 1.

b. Purpose - To determine the suitability of subject ambulance (Army Serial No. 710595) for use in Hot Climates.

2. DISCUSSION:

a. The subject ambulance was constructed with insulated walls in an effort to reduce inside temperatures. (For description of insulated ambulance see Desert Warfare Board, Project No. 61-1. Preliminary Report, Truck 3/4 Ton, 4 x 4 Ambulance with Improved Body Insulation.)

b. The inside temperature of a closed ambulance exposed to full sunlight is raised markedly over that of the outside air unless ventilation of considerable capacity is provided to carry away the absorbed solar heat. Under desert conditions, for example, with high ambient temperature and continuous solar radiation, the inside temperature may become intolerable.

c. The use of insulation alone as a means of keeping down inside temperatures is of limited value, since, with continued exposure to constant radiation, the air temperature in a closed vehicle will reach an equilibrium level which eventually will be the same regardless of the quality of insulation. In practice, radiation and outside temperatures are not constant. Both increase from minimum values in the early morning to maximum levels near noon; the inside wall and air temperatures rising to reach maximum values an hour or more after peak outside conditions. An insulated ambulance, in contrast to the standard vehicle, will exhibit a lower rate of temperature increase during the morning hours and also a lower rate of decrease in the afternoon. The lag in heat flow will thus result in a somewhat lower maximum inside temperature during the period of outside temperature rise but the temperature will remain elevated above the outside level for a longer period in the afternoon.

d. The benefits to be derived from improved insulation are more striking in a vehicle equipped with a refrigeration system than in a closed ambulance without ventilation, since with cooling, there is a constant extraction of heat at a rate which is high relative to the heat transfer rate into a simple closed vehicle.

e. Details of procedures and results are given in the Appendix.

3. CONCLUSIONS:

a. Under static conditions, the application of improved insulation to ambulance walls does not reduce interior air temperatures to desirable levels.

b. In hot climates, reduction of temperature within the ambulance to an acceptable level for comfort of occupants requires the use of mechanical refrigeration. Wall insulation is desirable in order to keep the size of the cooling equipment at a minimum.

c. The excess temperature within an ambulance over that of the outside air can be kept at a minimum if adequate wall insulation is employed in conjunction with forced ventilation.

4. RECOMMENDATIONS:

a. That the use of improved wall insulation alone, as exemplified by subject vehicle, not be considered adequate for temperature control within ambulances.

b. That, if reduction of temperature below the outside level is to be achieved, mechanical refrigeration plus adequate wall insulation be provided.*

c. If mechanical refrigeration cannot be employed, that wall insulation plus forced ventilation be provided.

---

* See Project No. 2-29, Final Report on Test of Truck, 3/4 Ton, Refrigerated Ambulance. May 15, 1943.

Submitted by:

Lieut. Robert H. Walpole, SnC

APPROVED Willard Machle

WILLARD MACHLE
Colonel, Medical Corps
Commanding

2 Incl.

#1 - Authority
#2 - Appendix with Tables 1 & 2 and Figs. 1 & 2

In Reply Refer To:
GNWDB P-61-1

DESERT WARFARE BOARD
Desert Training Center
CAMP YOUNG, CALIFORNIA

File:

January 22, 1943

SUBJECT: Report of the Desert Warfare Board.

TO : Commanding General, Army Ground Forces, (Attention: Chief of Requirements Division) THRU: Military channels.

1. There is attached a Preliminary Report on test of Truck, 3/4-ton 4x4 Ambulance with Improved Body Insulation as conducted by this Board.

/s/ D. B. Sanger
/t/ D. B. SANGER
Colonel, (CAC) Inf.
President

Incl:
DWB Report P 61-1 (Preliminary)

Distribution:
Orig & 5 copies to Commanding General, Army Ground Forces
1 copy thru: Commanding General, Army Ground Forces to: Surgeon General
1 copy to Commanding General, Armored Force
1 copy to Commanding General, Desert Training Center
1 copy to President, Armored Force Board
1 copy - file
1 copy in reserve

319.1/1 GNWAG 1st Ind. CJP/jcdw
HEADQUARTERS DESERT TRAINING CENTER, Camp Young, California, January 25, 1943.

TO: Commanding General, Army Ground Forces, Washington, D.C.

/s/ C. J. P.
/t/ C. J. P.

Incls:
DWB Report P 61-1 (Preliminary)

Incl #1

451.8/38-GNRQT-8/30249 2nd Ind.
(1-22-43)
HQS., ARMY GROUND FORCES, Army War College, Washington, D. C.

TO: Commanding General, Services of Supply, Washington, D. C.
(ATTN: Development Branch, Requirements Division)

1. For your information.

2. Pending receipt of other recommendations from the Surgeon General, the recommendation of the Desert Warfare Board to discontinue further tests until the advent of summer temperatures will be approved. Upon completion of such tests, final report and recommendations will be forwarded to your headquarters.

For the COMMANDING GENERAL:

/s/ James D. Tanner
/t/ JAMES D. TANNER
Lt. Col.,A.G.D.
Asst. Ground Adj. Gen.

1 Incl (quint)
(Sextl & septl w/d)

SUBJECT: Report of the Desert Warfare Board - Truck, 3/4-Ton, 4x4, Ambulance with Improved Body Insulation.

SPRMD 451.8 (1-22-43) 3rd Ind. JHA/aet
71798

Headquarters, Services of Supply, Washington, D. C.

To: The Commanding General, Army Ground Forces, Attention: Requirements Section, Development Division.

1. In order that an expedited and controlled test of the Ambulance, 3/4-Ton, 4x4, with Improved Body Insulation, might be conducted, it is requested that the subject vehicle be shipped to the Armored Force Medical Research Laboratory, Fort Knox, Kentucky, for test.

For the Commanding General:

W. A. WOOD, JR.,
Brigadier General, General Staff Corps,
Director, Requirements Division.

1 Incl. n/c (Quad)

Incl #1

451.[illegible]/31077 4th Ind.
(1-22-43)

HQ., ARMY GROUND FORCES, Army War College, Washington, D. C.

TO: Chief of the Armored Force, Fort Knox, Kentucky

1. In reference to the proposal to test the subject vehicle at the Armored Force Medical Research Laboratory, your attention is invited to the fact that the use of aluminum foil is an attempt to insulate the vehicle from the infra-red rays of the sun. For this reason, it would appear doubtful that such conditions could be duplicated in an artificially heated testing chamber.

2. Your comments and recommendations are requested.

By command of LT. GENERAL McNAIR:

/s/ James D. Tanner
/t/ JAMES D. TANNER
Lt. Col., A.G.D.
Asst. Ground Adj. Gen.

1 Incl.
(dupl, tripl, quad, w/d)

319.1/2 (1/22/43) GNOHD 5th Ind.

HEADQUARTERS ARMORED FORCE, Fort Knox, Kentucky, February 25, 1943.

To: Commanding General, Army Ground Forces, Army War College, Washington, D. C.

1. Rates of temperature rise in the two vehicles did not differ greatly in the test reported. More significant differences might be obtained with greater air exchange in the ambulances. It is to be anticipated that the aluminum foil treatment would greatly reduce radiation gain. The Armored Force Medical Research Laboratory is prepared to test subject vehicle under controlled conditions of temperature, rate of ventilation, and simulated solar radiation. Radiation lamps are being installed within the next three (3) weeks. Vehicles may be shipped to arrive on or about March 20, 1943.

2. Permission is requested to paint the exterior of the vehicle with infra-red reflector paints if added protection against radiation is indicated by initial test.

3. Recommend approval of request contained in 3rd Indorsement.

For the Commanding General:

/s/ C. M. Wells
/t/ C. M. WELLS,
Lieut. Colonel, A.G.D.,
Assistant Adjutant General

1 Incl: n/c

Incl #1

451.8/83-GNRQT-8/32963 (1-22-43) 6th Ind.

HQS., ARMY GROUND FORCES, Army War College, Washington, D. C.

TO: President, Desert Warfare Board, Camp Young, Indio, California

It is desired that the subject vehicle be shipped without delay to the Armored Force Medical Research Laboratory, Fort Knox, Kentucky and that this correspondence be forwarded to the Chief of Armored Force, Fort Knox, Kentucky for his information and necessary action.

By command of LT. GEN. McNAIR:

/s/ J. R. Dryden
/t/ J. R. DRYDEN,
Lt. Col., A.G.D.
Asst. Ground Adj. Gen.

1 Incl. n/c

GNWDB 7th Ind. TCB/jq

DESERT WARFARE BOARD, Desert Training Center, Camp Young, California, March 25, 1943.

TO: Chief of Armored Force, Fort Knox, Kentucky.

1. In compliance with 6th Indorsement above, 3/4-Ton Insulated Ambulance shipped on March 25, 1943, on Bill of Lading #WL-8980949, NYC Car #616691.

For the PRESIDENT:

/s/ Thomas C. Brannum
/t/ THOMAS C. BRANNUM
Captain, Infantry
Recorder

1 Incl. n/c

Incl #1

319.1/2 (1-22-43) GNCMD 8th Ind. S-4-28-43.

HEADQUARTERS ARMORED FORCE, Fort Knox, Kentucky, April 1, 1943.

To: Commanding Officer, Armored Force Medical Research Laboratory, Fort Knox, Kentucky.

For your information and return.

By command of Lieutenant General DEVERS:

/s/ C. M. Wells
C. M. WELLS,
Lieut. Colonel, A.G.D.,
Assistant Adjutant General

1 Incl: n/c.

Incl #1

1. TEST CONDITIONS:

Temperatures inside the subject vehicle and in a standard ambulance were compared under equal conditions of exposure to a simulated desert atmosphere. Both vehicles were closed and stationary with no outside air movement and no mechanical ventilation. Dry heat was employed with hourly variation in radiation approximating the solar heat load and changes in air temperature simulating the average diurnal temperature curve for the California desert (See Fig. 1). Radiation was provided by a bank of heat lamps mounted below the ceiling of the hot room, and the diurnal cycle obtained by hourly changes in the number of lamps in operation. The intensity of radiant heat reached a maximum of 320 Btu per sq. ft. per hour, which corresponds closely to the intensity of solar radiation at midday on July 21st at latitude 30°N. Relative humidity was approximately 25%.

2. RESULTS:

Comparative temperature-rise curves for the two ambulances are shown in Fig. 1. Some lag will be observed in the rate of increase of air temperature inside the insulated ambulance as compared with the standard vehicle. Shortly after noon, the insulated ambulance air temperature was 40° above the outside temperature whereas in the insulated vehicle, the temperature difference was less than 25°.

The effect of the insulation in reducing the rate of heat flow into the test vehicle is further demonstrated by the constantly greater temperature difference between inside skin and inside air in the standard as compared with the insulated ambulance. From the temperature gradients within the wall and from the wall to the inside air, it is possible to calculate the relative improvement in insulation obtained in the test vehicle. Heat flow equations are indicated in Fig. 2 for a section of wall exposed on one side to radiation. A major portion of the heat absorbed is lost externally by radiation and convection. Of the remainder, some is stored in the wall and the rest is transferred through to the inside air. Toward noon, as shown in Fig. 1, the temperature-rise curves become approximately horizontal and wall storage approaches zero. Under this condition of approximate thermal equilibrium, we may write:

$$dh_3 = U_w(t_1 - t_4) = f_2(t_4 - t_5)$$

Since both vehicles were closed and were equally tight, we may assume equal ventilation and equal values of f_2, the wall to air resistance. Thus, the value of the coefficient of the wall of the insulated vehicle bears the

Incl #2

following relation to the wall coefficient of the standard vehicle:

$$\frac{U_w}{U'_w} = \frac{(t_4 - t_5)\,(t'_1 - t'_4)}{(t_1 - t_4)\,(t'_4 - t'_5)}$$

Where U_w, t_1, etc. and U'_w, t'_1, etc. refer to the insulated and standard vehicles respectively. The average ratio, calculated in this way for sun time 1030 to 1200, was found to be 0.33 (Table 1). Thus, the effect of the improved insulation was to increase the resistance to heat flow through the walls some 3 times over that of the standard vehicle.

This degree of improvement in wall insulation does not produce a directly proportional reduction in actual heat transfer since the air to wall resistance, which makes up part of the overall transfer coefficient, remains the same. Thus, the temperature rise in the insulated tank was reduced about 40% as compared with a 66% improvement in the wall insulation alone.

The benefits to be derived from improved wall insulation are not fully demonstrated by a static test in which there is a negligible passage of heat through the vehicle walls. Since it is the rate of heat flow rather than the intensity of heat (temperature) which is involved, one would expect with increased ventilation or refrigeration a relatively greater benefit from improved wall insulation than under the static conditions employed in this test. This is shown by the following approximate calculations:

1. Assume thermal equilibrium and maximum intensity of solar radiation of 320 Btu/sq. ft./hr. The heat lost by external radiation may be taken as 100 Btu/sq. ft./hr. (outside skin temp. = 170°; temp. of surroundings = 106°), leaving 220 Btu/sq. ft./hr. to be transferred in part to the inside and part to the outside air. The balance between these two avenues of heat transfer is expressed by the equation:

$$\left(\frac{1}{f_1} + \frac{1}{U_w} + \frac{1}{f_2} + \frac{1}{Sa\ Wa}\right)\ dh_3 = \frac{dh_1 + dh_3}{f_1}$$

where f_1 and f_2 are the outside and inside air film resistances; U_w, the wall coefficient; Wa, the weight of air flowing through the vehicle per hour per sq. ft. of wall surface; S_a, the specific heat of air. Assume air film resistance values of 3.0 and 1.5 for the outside and inside walls, respectively, a wall coefficient of 0.5 for the standard and 0.17 for the insulated vehicle and a minimum rate of ventilation of 1.0 lb. of air per sq. ft. per hour (35 cfm). Entering these values in the equation, the rates of heat transfer, dh_1 and dh_3, are determined and from them the skin and air temperatures may be calculated. The resulting values for the static vehicles, given in Case I, Table 2, are in fair agreement with the data in Fig. 1. In order to show the comparative performance of the two vehicles with a relative high rate of ventilation (350 cfm), the values in Case II have been calculated. Under this condition, the excess temperature within the test vehicle is found to be only 45% of that developed in the standard ambulance as compared with 62% under the static condition. It will be observed that the effect of increased ventilation is relatively

Incl #2

much greater than the benefit derived from the improved wall insulation.

It is also significant to note that in neither case is the desired objective accomplished, namely, the reduction in inside temperature to a level which will assure patient comfort. Since the temperature to be achieved in ambulances is below the ambient temperature in hot climates, refrigeration is required and, in order to keep the capacity and power consumption of the cooling system within reasonable limits, adequate insulation of the walls of the vehicle should be provided.

Incl #2

RELATIVE HEAT TRANSFER THRU WALLS OF INSULATED AMBULANCE
AS COMPARED WITH STANDARD VEHICLE

Temperature	Sun Time				Sum
	1030	1100	1130	1200	
t_1	139°F	147°F	157°F	161°F	
t_4	114	119	124	129	
t_5	112	118	123	127	
t_1-t_4	25	28	33	32	118
t_4-t_5	2	1	1	2	6
t_1'	151	160	166.5	172	
t_4'	127	134	138	142	
t_5'	123	131	133.5	137	
$t_1'-t_4'$	24	26	28.5	30	108.5
$t_4'-t_5'$	4	3	4.5	5	16.5
U_w/U_w'	.43	.31	.19	.375	.333

Incl #2

TABLE 2

Calculated Skin and Air Temperatures in Insulated and Standard Ambulances, under Static Conditions and with Incrsased Ventilation.

	Case I Static Condition		Case II With Ventilation at 350 cfm	
	Standard	Insulated	Standard	Insulated
Outside Air	$106^{\circ}F$	$106^{\circ}F$	$106^{\circ}F$	$106^{\circ}F$
Outside Skin	176	177	172	176
Inside Skin	155	137	129	117
Inside Air	148	132	115	110
Air Temp. Rise	42	26	9	4

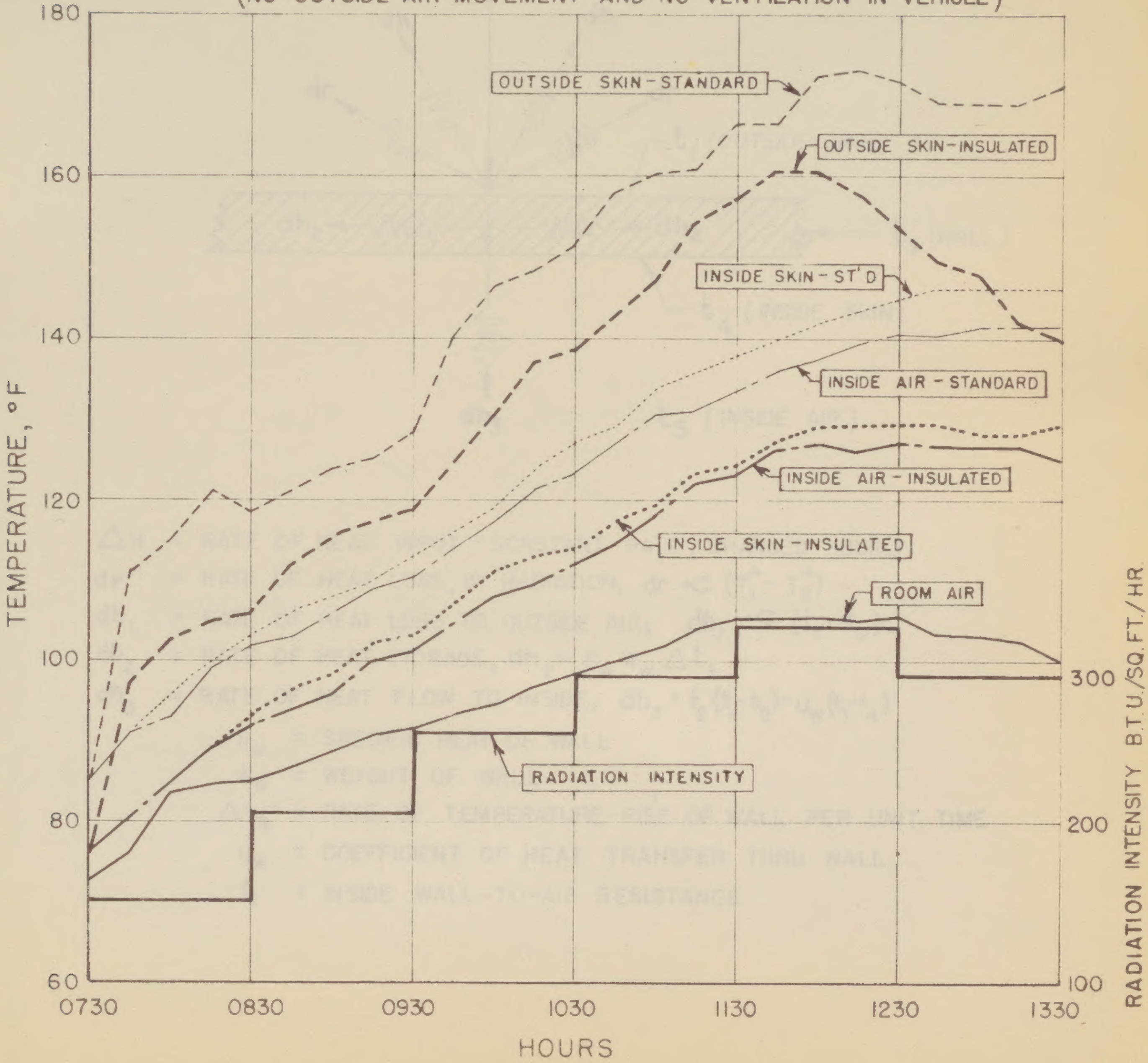
Incl. #2

FIG. 1

COMPARISON OF WALL AND INSIDE AIR TEMPERATURES
INSULATED VS STANDARD AMBULANCE

EXPOSED TO SIMULATED DESERT HEAT AND SOLAR RADIATION

(NO OUTSIDE AIR MOVEMENT AND NO VENTILATION IN VEHICLE)

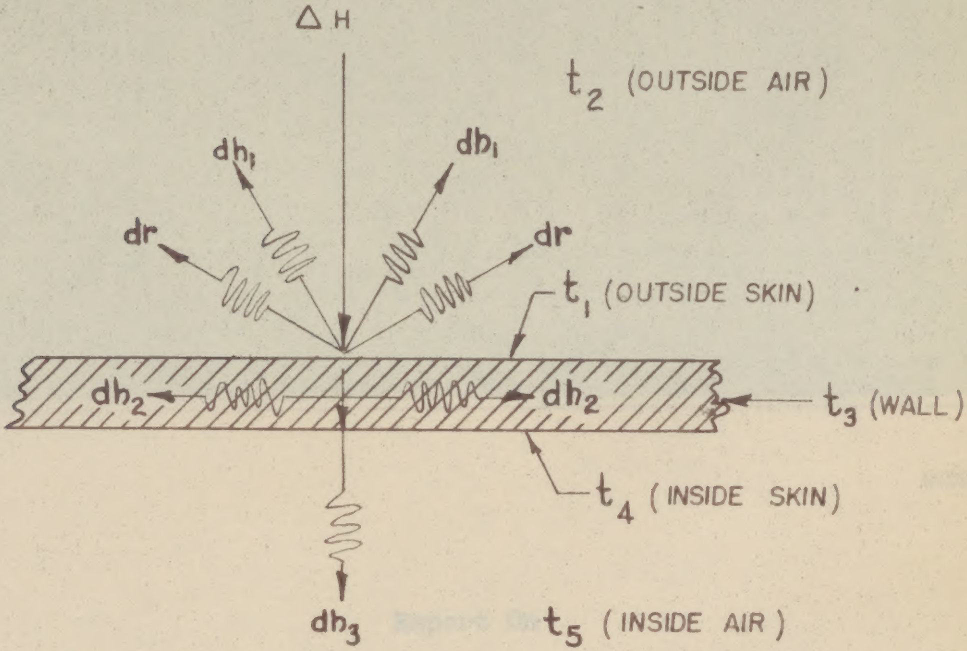


Incl. # 21

FIG. 1

FIG. 2

SCHEMATIC DIAGRAM OF HEAT FLOW THROUGH WALL EXPOSED TO RADIATION ON ONE SIDE



ΔH = RATE OF HEAT INPUT - CONSTANT RATE, CHANGED HOURLY

dr = RATE OF HEAT LOSS, BY RADIATION; $dr \propto (T_1^4 - T_2^4)$

dh_1 = RATE OF HEAT LOSS TO OUTSIDE AIR; $dh_1 \propto (t_1 - t_2)$

dh_2 = RATE OF HEAT STORAGE, $dh_2 = S_W W_W \Delta t_3$

dh_3 = RATE OF HEAT FLOW TO INSIDE, $dh_3 = f_2 (t_4 - t_5) = U_W (t_1 - t_4)$

S_W = SPECIFIC HEAT OF WALL

W_W = WEIGHT OF WALL

Δt_3 = RATE OF TEMPERATURE RISE OF WALL PER UNIT TIME

U_W = COEFFICIENT OF HEAT TRANSFER THRU WALL

f_2 = INSIDE WALL-TO-AIR RESISTANCE

Incl. #2